

Effect of ventricular function on left ventricular ejection time in aortic stenosis

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SUMMARY Since recognition of factors which modify the duration of ejection in aortic stenosis is of clinical importance, the relations among rate-corrected left ventricular ejection time, aortic valve area, and determinants of ventricular performance were studied in 54 catheterised patients.

In patients with a normal cardiac index, increasing duration of ejection was linearly related to increasing obstruction. In patients with failing ventricles, on the other hand, the ejection time was less prolonged, and the duration of ejection was unrelated to valve area. At fixed valve area, relation with cardiac output, stroke volume, heart rate, mean aortic valve pressure gradient, mean aortic pressure, and left ventricular end-diastolic pressure could not adequately explain the observed scatter in ejection time. This suggests a multifactorial basis for the wide range of ejection times observed with severe aortic stenosis.

Prolongation of the rate-corrected left ventricular ejection time (LVET) is associated with significant valvular aortic stenosis and is of clinical use in evaluating patients with this disorder (Katz and Feil, 1925; Benchimol *et al.*, 1960; Bonner *et al.*, 1973). Unfortunately, the tendency for the LVET to increase with decreasing aortic valve area is accompanied by a wide scatter of ejection time values, particularly with severe obstruction (Bache *et al.*, 1973; Kligfield *et al.*, 1977). This scatter limits the clinical value of the technique for predicting valve area.

Identification of additional factors which affect the duration of ejection in aortic stenosis is therefore of importance in the evaluation of these patients. For example, it has been shown that though additional aortic regurgitation tends to prolong further the LVET in aortic stenosis, the presence of either coincident significant mitral stenosis or severe mitral regurgitation may normalise the LVET in patients with even severe aortic stenosis (Kligfield *et al.*, 1977).

In heart disorders not affecting left ventricular outflow, LVET shortening is the rule. Though depressed left ventricular function of primarily ischaemic or myopathic aetiology shortens the LVET (Weissler *et al.*, 1961; Heikkilä *et al.*, 1971; McConahay *et al.*, 1972), it has been shown that

congestive failure secondary to aortic stenosis is characterised by persistence of LVET prolongation (Bonner and Tavel, 1973). However, despite the expectation that ventricular dysfunction should modify the duration of ejection, the effect of ventricular performance on the LVET in aortic stenosis has yet to be documented and clarified.

Accordingly, we have examined the effect of ventricular function on the prolonged LVET in aortic stenosis with two questions in mind. First, does depressed ventricular performance modify the tendency of LVET to lengthen with increasingly severe obstruction? If so, second, might comparison of LVET at fixed valve area with cardiac output, heart rate, stroke volume, pressure gradient, mean aortic pressure, and left ventricular end-diastolic pressure reveal a determinant of performance that would adequately explain the observed scatter in LVET?

Methods

The records and tracings of 100 catheterised adult patients with valvular aortic stenosis and no additional valve lesions were examined. Of these, 46 were excluded from the study: 27 had technically suboptimal pressure tracings for the purpose of the study, and 19 were excluded because of intra-ventricular conduction abnormalities (QRS duration

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100 ms) known to affect the time intervals.

The study population thus consisted of 54 adult patients with pure valvular aortic stenosis, no additional valve lesions, normal interventricular conduction, and optimal pressure data. Calculated aortic valve orifice area ranged from 0.2 to 1.4 cm².

Left heart catheterisation was performed with Sones catheters via femoral puncture, using a fluid-filled pressure transducer. All pressures used in the calculations were obtained within 10 to 15 beats of left ventricular to aortic root pullback. Right heart catheterisation was performed with Courmand catheters. Cardiac output was calculated from measured, not assumed, oxygen consumption and measured oxygen contents.

LVET was measured in msec from the initial rapid rise to the incisura of the central aortic pressure tracing. The LVET derived from the central pulse has been shown to correlate well with the externally measured carotid ejection time (Weissler *et al.*, 1961; Martin *et al.*, 1971). An average value of four beats was used. Only two patients included in this study were in atrial fibrillation. To minimise the effect of varying cycle length on LVET, only cases in which four cycles of similar length were present, approximating 800 msec, were included, and the average heart rate used for correction. Rate correction was performed according to the standard regression data of Weissler *et al.* (1969): for men, LVET (ms) = measured ejection time (ms) + 1.7 × heart rate.

Valve area was calculated from the standard Gorlin relation, using a constant of 44.5 (Gorlin and Gorlin, 1951).

LVET was compared with calculated aortic valve area for the entire group. To examine the effect of ventricular function on LVET, patients were divided into good (≥ 2.8 l/min per m²) and poor (< 2.8 l/min per m²) function subgroups, where 2.8 l/min per m² represents one standard deviation below laboratory mean normal.

To determine whether a single variable of ventricular performance might account for LVET scatter at fixed valve area, the total patient population was divided by valve area: 0.2–0.4 cm², 0.5–0.7 cm², and 0.8–1.4 cm². Within each group, linear regression correlation was sought to relate LVET with either cardiac output, stroke volume, heart rate, mean aortic pressure gradient, mean aortic pressure, or left ventricular end-diastolic pressure.

Results

Rate-corrected ejection times for the total population of 54 patients were plotted against calculated

aortic valve areas as shown in Fig. 1. A regression line relating the two variables, $LVET = -22AVA + 462$, confirms the obvious poor correlation ($r = -0.250$, $P = NS$) for the total aortic stenosis population. At any given valve area, a wide range of LVET values exists, suggesting that additional determinants of ejection time are operative. This scatter is most obvious at smaller orifice areas, so that, indeed, no reliable prediction of valve area appears possible for a single LVET determination.

However, when patients were separated by cardiac index into a good function group (≥ 2.8 l/min per m²) and poor function group (< 2.8 l/min per m²), a distinct difference in LVET variation with aortic valve area is seen (Fig. 2). Patients with good ventricular performance tend to have higher values of LVET at smaller valve areas, while patients with poor performance show distinct scatter. As expected, poor ventricular performance was more common at smaller valve area.

In the 20 patients with good ventricular function, LVET lengthened as aortic valve area (AVA) became smaller. The linear regression equation relating the variables, $LVET = -49 AVA + 490$, reveals significant correlation ($r = -0.663$, $P < 0.01$). However, in 34 patients with poor ventricular per-

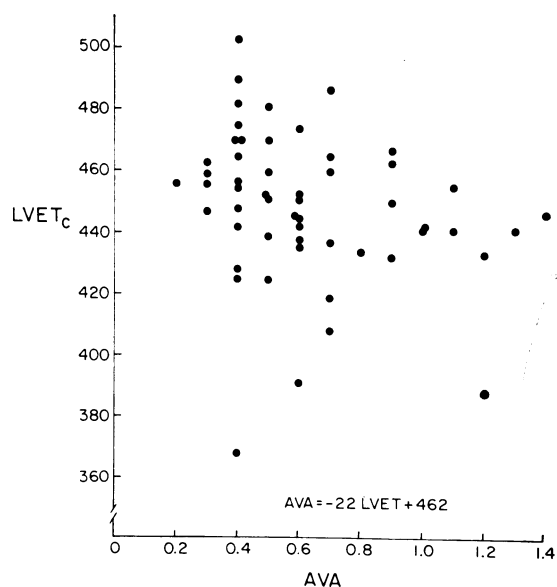


Fig. 1 Rate-corrected left ventricular ejection time (LVET), in msec, in 54 patients with pure aortic stenosis. Linear correlation with valve area (AVA) is poor for the total group, with wide scatter most apparent at smaller orifice size.

formance, correlation was poor ($r = -0.090$, $P = \text{NS}$) for the equation relating LVET with AVA (Fig. 2).

Comparison of the regression lines in Fig. 2 shows that at any given aortic valve area, the ejection time in patients with pure aortic stenosis and good ventricular function tends to be greater than in patients with compromised ventricular performance. In patients with a normal cardiac index, increasing LVET suggests increasing valvular obstruction. For patients with a reduced cardiac index, however, no prediction of valve area is possible from the LVET.

In an attempt to determine which specific determinant of ventricular performance might account for the LVET scatter at fixed valve area, patients were subgrouped by calculated orifice size: $0.2\text{--}0.4\text{ cm}^2$, $0.5\text{--}0.7\text{ cm}^2$, and $0.8\text{--}1.4\text{ cm}^2$. Linear regression equations were calculated for each valve area group and for the total population, relating LVET with cardiac output, stroke volume, heart rate, mean aortic pressure gradient, mean aortic pressure, and left ventricular end-diastolic pressure. The results are shown in the Table. In every case, correlation was poor, with no significant relation found that

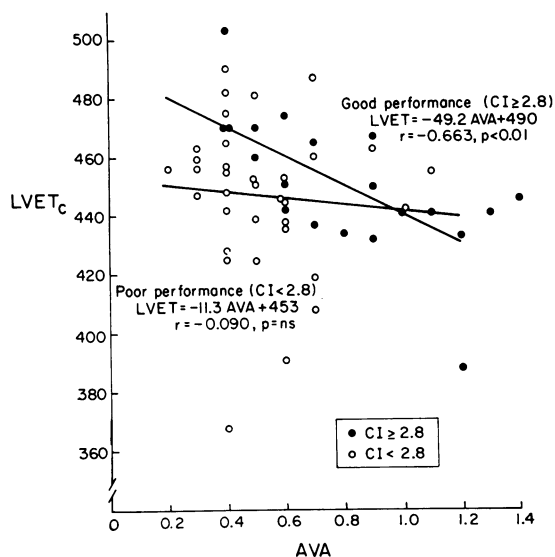


Fig. 2 Effect of ventricular function. In patients with a cardiac index ≥ 2.8 l/min per m^2 (closed circles), LVET increases as aortic valve area (AVA) decreases, while in patients with poor function (open circles), LVET prolongation is reduced and scatter is obvious. Linear regression relating LVET and AVA demonstrates significant correlation of patients with good function, but no relation in patients with reduced cardiac index.

could explain LVET variance at fixed valve area on the basis of a single measured determinant of ventricular function.

Discussion

Since prolonged duration of ejection is a useful sign of valvular aortic stenosis, recognition of factors that modify ejection time in this disorder is of importance. Previous work had documented the significant effect of additional valve lesions on the LVET in aortic stenosis (Kligfield *et al.*, 1977). Though it is generally expected that increasing obstruction be accompanied by increasing LVET, it is well established that ventricular dysfunction of ischaemic or myopathic aetiology shortens the ejection time (Weissler *et al.*, 1968, 1969; Parisi *et al.*, 1971; Bonner *et al.*, 1973). The interaction of these factors requires clarification.

The data in this study demonstrate that at any valve area, the LVET in aortic stenosis tends to be less prolonged in patients with reduced cardiac index. The increasing LVET expected with increasingly severe outflow obstruction is reliably observed only in patients with preserved ventricular performance. In patients with compromised function, no useful prediction of the severity of aortic stenosis is possible based on LVET because of the wide scatter of ejection time in this group.

Variable ventricular performance therefore appears to account for some of the scatter in LVET at fixed valve area seen in this and in previous studies (Bache *et al.*, 1973; Kligfield *et al.*, 1977). This effect of function on the prolonged ejection time in aortic stenosis should be considered in evaluating the LVET in outflow obstruction. Understanding of this LVET effect would be of even greater clinical usefulness in combination with another technique for the estimation of aortic valve area, such as two-dimensional echocardiography, since deviation from expected LVET values might provide quantitative insight into specific aspects of ventricular performance.

Table Lack of correlation of LVET and individual determinants of LV performance

	r values (correlation with LVET)			
	Aortic valve area subgroups (cm^2)			
	0.2-0.4	0.5-0.7	0.8-1.4	Total group
Cardiac index	0.371	0.372	0.183	0.133
Stroke index	0.182	0.324	-0.178	-0.022
Heart rate	0.194	-0.013	0.265	0.216
LV end-diastolic pressure	0.063	0.072	-0.106	0.099
Mean aortic pressure	0.332	0.069	-0.301	0.022
Mean pressure gradient	0.058	-0.036	-0.044	0.152

It is therefore disappointing that no single index of ventricular function was found to correlate with LVET within narrow valve area groups. Though LVET is significantly dependent on stroke volume, it is also dependent on factors affecting contractility, preload, and afterload (Braunwald *et al.*, 1958; Heikkilä *et al.*, 1971; Martin *et al.*, 1971). For this reason, correlation was sought not only with stroke volume, heart rate, and cardiac output, but with mean aortic pressure gradient, mean aortic pressure, and left ventricular end-diastolic pressure as well. However, no single variable explained the data. Since the range of LVET values found, especially at smaller orifice areas, far exceeds measurement error with this technique, it appears that the effect of function on LVET has a multifactorial basis.

Examination of the Gorlin relation provides an interesting, but speculative, insight into this problem. As is well known, the aortic valve area is calculated from the measured cardiac output, systolic ejection period, and pressure gradient (Gorlin and Gorlin, 1951). Rearrangement of terms and application of the Weissler rate regression data reveals that at a fixed valve area, the rate-corrected

$$LVET = k' SV / \sqrt{PG} PG + k'' HR$$

where SV is stroke volume, PG the mean pressure gradient across the aortic valve, HR the heart rate, and k' and k'' derived constants. From this relation, given the lack of correlation with single variables shown in this study, it appears that the variance of LVET with ventricular function depends on the manner in which heart rate modifies the ratio involving stroke volume and the square root of the pressure gradient. Quantitative investigation of how these relations vary with ventricular performance and valve area should provide further insight into the pathophysiology of aortic stenosis.

Despite the uncertainty about the mechanism, ventricular function is an important modifier of ejection time in aortic stenosis. In patients with a normal cardiac index, increasing duration of ejection is associated with increasing obstruction. In the failing ventricle, on the other hand, ejection time tends to be less prolonged, and the duration of ejection does not reflect the valve area.

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